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AUTOMATIC PATTERN RECOGNITION IN A
MULTI-SENSOR ENVIRONMENT

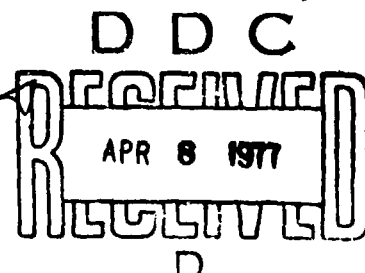
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For the Period
January 1, 1976 - December 31, 1976

U.S. AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
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20. ABSTRACT (cont'd.)

↓ recognition system to improve accuracy and reliability, the development of an image array processor for application to real time image identification, and the analysis of various features and authority file generation algorithms to identify properties which may reduce the training period. In addition an investigation was also carried out on the application of "fuzzy" automata to the scene segmentation problem. Finally, an application of the work carried out here was developed in the use of visual feedback for work piece positioning and control.

ABSTRACT

The work reported here, supported by the U.S. Air Force Office of Scientific Research under Grant AFOSR-76-2953 covers the period from January 1, 1976 to December 31, 1976. During this period a number of investigations were undertaken directed at the general goals of improving the accuracy, reliability and speed of visual recognition systems. Work was carried out on basically three different problems. The development of a multiple look sequential recognition system to improve accuracy and reliability, the development of an image array processor for application to real time image identification, and the analysis of various features and authority file generation algorithms to identify properties which may reduce the training period. In addition an investigation was also carried out on the application of "fuzzy" automata to the scene segmentation problem. Finally, an application of the work carried out here was developed in the use of visual feedback for work piece positioning and control.

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1. Introduction

The research accomplishments described in this final scientific report constitute the results of work supported by Grant AFOSR-76-2953 over the period January 1, 1976 to December 31, 1976. The work carried out over this period was directed at improving recognition algorithms developed during past work with primarily, two goals in mind:

1. improve recognition accuracy and general reliability, and
2. increase speed of identification for application to real time systems.

With these goals in mind three investigations were undertaken:

1. The modification of existing recognition algorithms to improve recognition accuracy and reduce identification time.
2. The development of an image array processor for application to real time feature extraction and general image processing problems.
3. The analysis of the behavior of these algorithms to better understand the feature selection and authority file generation problem.

The results of these investigations are briefly summarized in what follows.

A list of publications generated under this grant will be found in Section

3.

2. Research Accomplishments

The following five subsections describe the results of the major efforts undertaken which relate to the above research goals. Section 2.5 presents some results related to a potentially useful application area automated visual work piece position control. The details of these efforts may be found in the publications cited in Section 3 as well as research proposals associated with this grant and the previous Grant AF-AFOSR-71-2048 upon which the current work is based.

2.1 A Sequential, Multiple Look Visual Recognition System

In real time, visual pattern recognition systems, such as might be used for aircraft identification, decisions based upon a single observation of a target are far more prone to error than if such decisions are made on the basis of multiple target observations. In order to examine this situation more carefully a set of sequential recognition algorithms were developed and tested by application to a set of aircraft images obtained via a computer interfaced TV system. The authority files used consisted of 150 aircraft images for each of 12 aircraft types, giving a total of 1800 samples. The test sets, generated independently of the authority files, consisted of 10 look sequences for each of the 12 aircraft types, giving a total of 120 sequences. Each sequence consisted of 6 successive looks taken as the plane changed position relative to the camera in a normal "fly by" fashion.

Five sequential classification procedures were devised; maximum likelihood, majority class count, sum of confidence, selective k nearest neighbor and accumulated mk nearest neighbor. The recognition of an aircraft associated with a given sequence proceeded by making a

tentative identification at each look based on one of the above five sequential decisions rules. A confidence metric was then computed for each of the possible 12 classes. Using the ratio of the largest to the next largest confidence numbers, a stopping criteria was generated.

With the classifiers and authority files mentioned above, the test sets were examined to determine how well the various recognition systems performed. It was found that the sum of confidence classifier yielded an error rate of only 3.33% at the end of six looks. This was nearly four times better than for the maximum likelihood procedure and about twice as good as the next best classifier, the majority class count algorithm.

2.2 An Image Array Processor System

It has been proposed that the processing of real time images can be performed most efficiently when the structure of the processor closely resembles the structure of the data to be operated upon. Thus one would expect that image processing operations can be implemented more easily and faster within an array processor than in a normal serial processor. Such a processor has been constructed and a high level language has been developed for the real time manipulation of images.

2.2.1 The Array Processor

Basically, an array processor consists of a tessellation of the plane by processing elements, each executing the same instruction stream issued by a single central controller. Such an array processor has been constructed which is implemented as a finite 128 by 128 array of one bit binary processors with facilities built in for expansion 256 by 256. A

rectangular tessellation is used, with each processing element possessing connections to its eight nearest neighbors as well as to its own private accumulator and memory as shown in Figure 1.

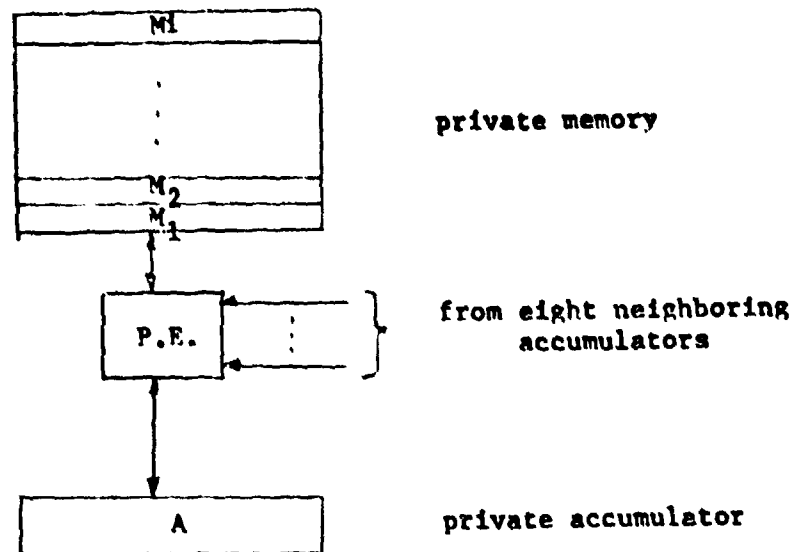


Figure 1. Array Processor Element

Each processing element can form any of the 16 possible Boolean functions of two variables via the Bus Function Generator (BFG) using any two of the following inputs: the present contents of its accumulator, the present contents of any of its memory cells, and a threshold function of the accumulators of its eight nearest neighbors, denoted $f(A)$. Specifically,

$$f(A) = 1 \quad \text{if} \quad \sum_{i=1}^8 A_i \cdot W_i \geq T$$

0 otherwise

where

$W_i \in \{+1, 0, -1\}$, the 8 weights

$A_i \in \{0, 1\}$, the i^{th} out of 8 nearest neighboring accumulators

$T \in [-8, 7]$, the threshold.

This organization is summarized in Figure 2. A bus oriented structure was used for maximum flexibility in interconnecting the various registers and for future expansion of additional I/O devices, such as a direct TV camera interface and various hard-wired masks. Inputs to the RFG consist of the Main (M) and Secondary (S) buses, each of which can be driven by any of eight possible devices selected under program control. Any or all of the devices can receive information from the Output (O) bus simultaneously, also selected under program control.

Instruction execution times are on the order of 10ms., as compared with almost two seconds on the array processor simulator presently running on the PDP-9. Image transformations of only moderate complexity consisting of perhaps 2000 operations required over an hour of computer time using the simulator. The time for such a transformation has been cut to 20 seconds with the array processor allowing experimentation with transformations which had been timewise impractical to attempt.

2.2.2 The High Level Language

A survey of the literature reveals the existence, either in hardware or simulation, of a number of image array processors at various universities and research centers. The structure of these processors tends to vary somewhat and even more so do the software packages required to utilize them. Consequently software developed at one installation cannot be easily transported for use on another array processor without

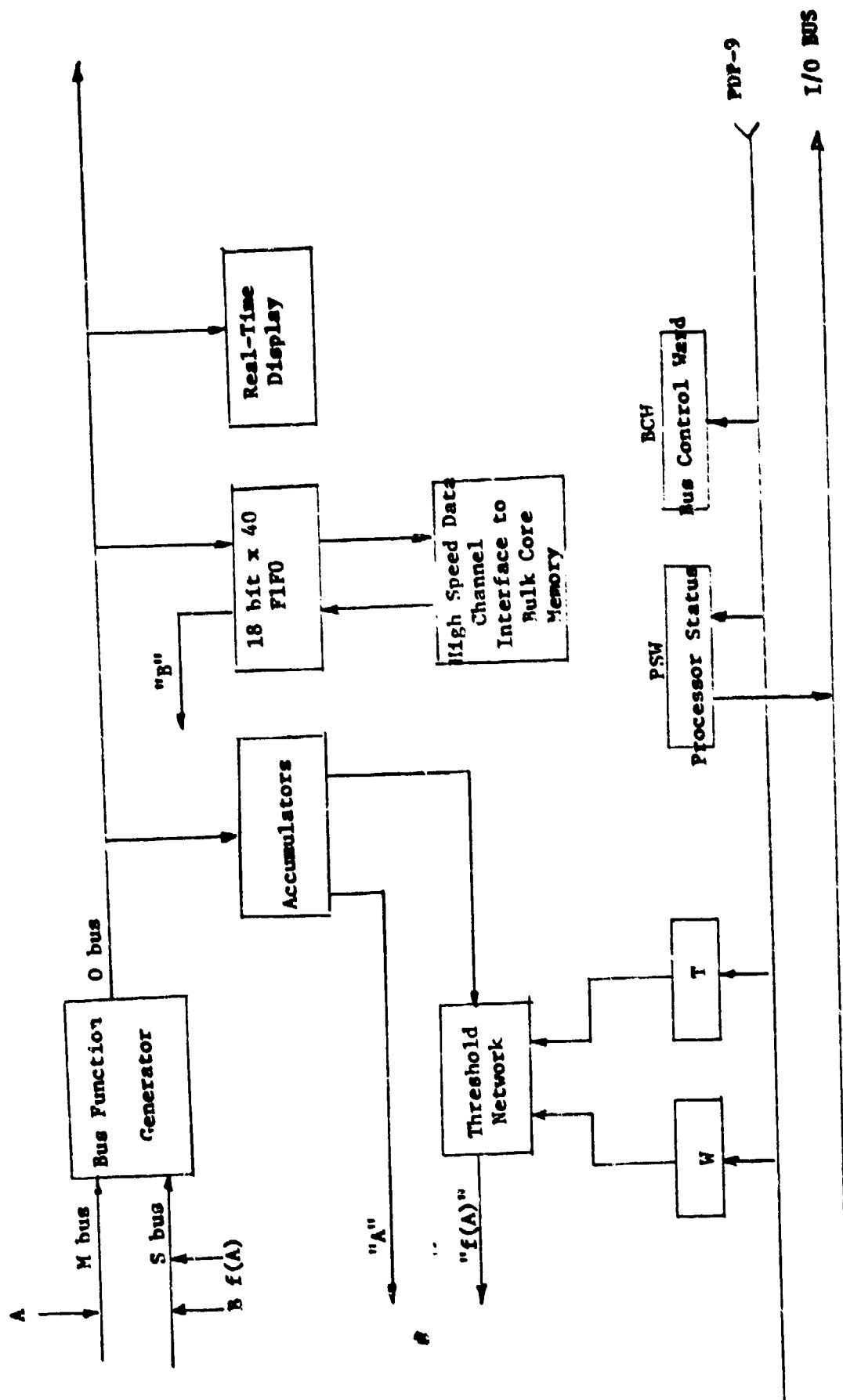


Figure 2.3 Array Processor Organization

major re-working of the software. This lack of image array processing software portability is a major obstacle to the sharing of software resources and building on previous research, a practice today commonplace with the usual sequential computer equipped with a high-level language.

With this goal of software portability in mind, a high-level array processing language has been developed and implemented for use with the binary image array processor. It is hoped that this language will comprise a step toward the eventual acceptance of a standard image array processing language, and at the same time influence the hardware design of future array processors to better execute classes of meaningful array processing operations as they emerge through programming experience.

The language was developed as a superset of standard FORTRAN IV because of the almost universal acceptance of FORTRAN. Since the array processing language is imbedded within FORTRAN, all the sequential computational and decision-making features of FORTRAN are available, as well as the additional array processing operations. Therefore the language was named the Fortran Array Processing Language, or FAPL.

In keeping with the original purpose of portability, the FAPL compiler itself was written with several unique features. The syntactic parser is a table-driven algorithm, with the syntactic language definitions contained within a table. The syntactic definition of FAPL was originally written in Backus Naur form (BNF).

An auxiliary program, written in FORTRAN for portability, was used to translate the BNF definitions into tabular form suitable for driving the parser. The parser itself was, again, written in FORTRAN.

Thus to transport the compiler to another installation also equipped with FORTRAN, the user need only make whatever changes are necessary in the original BNF definitions to fit the architecture of his array processor. He then has a working parser with as yet no re-programming having been required. With a working parser, the only re-programming required is the writing of the appropriate object code emitters to fit the specific machine requirements. These are written as subroutines invoked by the parser and can be made quite modular in operation.

Thus the compiler, as well as the FAPL language, has been developed with portability in mind, and it is hoped that these features will encourage the use of FAPL with other image array processors.

2.3 Algorithm Analysis

The recognition accuracy of the algorithms developed in this research has been extremely high. This has motivated a desire to investigate the various characteristics of these algorithms to determine the reasons behind this high degree of correctness. Two studies were carried out to examine this question. It has been determined by experimental observation that moment invariant features are very good for representing binary images. In order to determine just how well these features represent the images, methods were investigated for reconstructing the images from the moment invariants. This, then, constituted the first study.

The selection of samples to be included in the authority files is very important in maintaining a high degree of recognition accuracy. An earlier study, conducted under the previous grant, developed an adaption training procedure which yielded very small authority files and yet maintained high recognition accuracy. The second study under-

taken, then, was to investigate the behaviors of these training algorithms.

2.3.1 Image Construction from the Features

A method was investigated for constructing binary patterns from a given set of moments or moment invariants. The method involves constructing projections from the moments and, then, binary patterns from the projections. Sets of horizontal, vertical, and diagonal (at 45° and 135°) projections are derived from the moments. Some of these sets will be inconsistent, i.e., will correspond to no binary pattern. Tests for detecting many of these inconsistent projection sets were developed. An algorithm was developed for constructing patterns from those projection sets which seem to be consistent. This algorithm compares favorably with other existing algorithms as indicated by its application to several typical examples.

It was shown that the n -th order and all lower moments of a pattern are always determined by any $n+1$ projections of the pattern. The nature of pattern modifications which preserve projection sets and, hence, moments was also examined. Several necessary conditions for such modifications to exist for a given pattern were derived.

The construction method of this research has revealed that many binary patterns are uniquely determined (many others are almost uniquely determined) by their low order moments (1st, 2nd, and 3rd order). This can perhaps explain the successful use of moments as features for pattern recognition. The construction algorithm essentially solves certain types of underspecified simultaneous linear and nonlinear equations for binary and integer solutions, respectively.

2.3.2 Authority File Generation

In general, a three dimensional object may have an infinite set of feature vectors representing it, one for each of the infinity of viewing angles possible. These feature vectors are typically clustered in some more or less uniform fashion in the n dimensional feature space with one contiguous cluster for each object type. The authority file generation problem then amounts to finding a minimal set of feature vectors for each class which completely represent the class with respect to the other classes present. As long as the classes do not overlap it was shown that there always exists a finite number, n_i , of feature vectors for each class, N_i , which completely distinguish class N_i from all other N_j using a nearest neighbor classifier. It was also shown that this optimal set of n_i vectors is not unique but in fact there exist n_i subset from which these n_i vectors may be selected.

If the authority files are generated by a random selection of vectors from the n -dimensional clusters formed by each class, then an important question is how many such samples SM , must be taken to assure that at least one of the sets of n_i optimal vectors are included with probability θ . It was found that m is given by the solution to the equation

$$\prod_{j=1}^{n_i} (1 - k_j^m) = \theta$$

$$\text{for } k_j = 1 - \frac{V(P_j)}{V(n_i)}$$

where the P_j and the n_i subsets of cluster N_i from which the optimal

feature vectors can come and $V(A)$ represents the volume of set A in n space.

2.4 Syntactic Feature Extraction Via Fuzzy Automata

The use of syntactic features along with geometric features provides an improvement in recognition system performance. The main problems with syntactic features is that of extracting them from the field of view. An investigation was undertaken to determine whether the concept of fuzzy automata could be effectively applied to this problem. Basically the work was applied to the problem of extracting the edges of the intersections of the planar surface making up three dimensional polynomial figures such as boxes, pyramids, etc. These figures are not specially lit but rather are illuminated by normal room lighting. The major difficulty here is in locating and bounding entire surfaces. Under ambient room lighting the light intensity reflected from a surface will vary across the surface. Thus the fuzzy concept of "almost the same" light being reflected is used to identify the whole surface. Once each surface is found their relative positions can be used to find and specify the edges of these areas. Once this is done the object can be identified as to class and orientation with respect to the viewing axis.

Algorithms were developed to perform these tasks and experiments were done to check these algorithms. It was found that such concepts and procedures were very suitable to the syntactic feature extraction problem although much development work remains to be done.

2.5 Visual Target Position Control

Over the next decade or so, robots will probably play a

a larger role in materials handling, especially in hostile environments. Under normal circumstances such robots would be completely controlled by some human observer or preprogrammed to repeatedly perform some complex task. Situations exist where neither of these approaches is practical. For example, having a human on Earth control a remote vehicle on Mars is not feasible due to the communications time lag involved. Further no preprogrammed controller can be used in an environment where the surroundings are constantly changing. For these and other reasons a study was carried out to determine the efficacy of using visual feedback to control a two link system. The system consisted of a mechanical leg having two joints controlled by a computer. Also connected to the computer was a TV system which provided the visual feedback. Algorithms were developed to identify the position of each link in the leg relative to the TV camera optical axis on the basis of the TV image of the leg input to the computer. These algorithms were then extended to cause the leg to move from its initial position to any desired position in the field of view using the TV camera to measure the position and trajectory of the leg at each instant of time.

Experiments were performed to cause the leg to move in complex paths such as circles, figure eights, etc. These experiments and the algorithms developed demonstrate effectively that visual feedback may be used the control of remote systems.

3. Publications

All of the work described above has been prepared for publication in some form. The following list represents all of the publications produced under this year's grant as well as those produced under the

preceeding grant. Items submitted for publication or which are in preparation for publication and creditable to the grant are also listed. Publications appearing during the period of Grant AFOSR-76-2953 or are being prepared for publication under this grant are marked with an asterisk (*).

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3. Dudani, S. A., Moment Methods for the Identification of Three-Dimensional Objects from Optical Images, M.S. thesis, The Ohio State University, Columbus, Ohio, August 1971.
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5. Hawkins, T. C., PICTUR--A Computer Program for Description, Manipulation, and Display of Straight Line Drawings, M.S. thesis, The Ohio State University, Columbus, Ohio, June 1972.
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7. Butler, J. T., Networks of Two-Input Flexible Cells--A Study of Logical Properties and Techniques for Synthesizing Realizable Functions, Ph.D. dissertation, The Ohio State University, Columbus, Ohio, March 1973.
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- *40. Barre, J. L., Television Scene Analysis with Application to Computer Control of a Two Link System, M.S. thesis, The Ohio State University, Columbus, Ohio, December 1976.
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